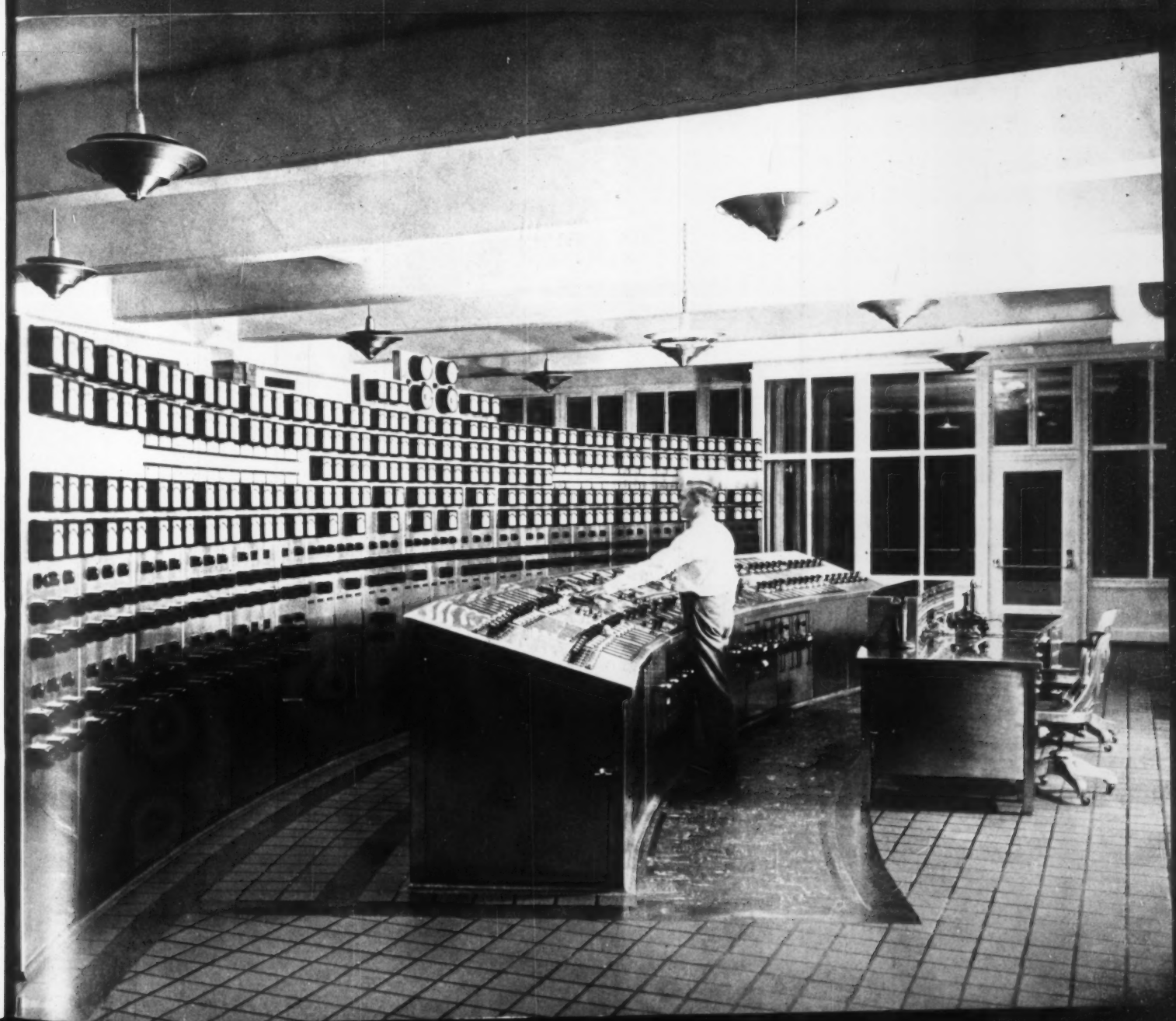
Instruments

THE MAGAZINE OF Measurement and Control

Vol. 11
SEPT.
1938
No. 9



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Designed for dependability, ruggedness and operating convenience—the new Model 9-TIC, TAG INDICATING CONTROLLER is presented in a stout, weather-proof, aluminum case—beautifully finished in black enamel and chromium.

The distinctive modern style of this new instrument is in pleasing agreement with the advanced principles and approved standards of TAG Air-operated Control which has served industry so successfully for many years.

All the latest TAG developments, including the Interchangeable, Calibrated Tube System that can be replaced with surprising facility, the Safety Link for range protection, Pointer Arm Brackets with bearings at each end, all important parts made of stainless steel and many other refinements you would expect to find in a TAG Instrument are present in this reliable Indicating Controller.

There's a new Bulletin No. 1175-I which describes both the "On-Off" and Throttling models in this TAG Indicating Controller line . . . we will be pleased to send it to you upon request.

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Park & Nostrand Ave's., Brooklyn, N. Y.

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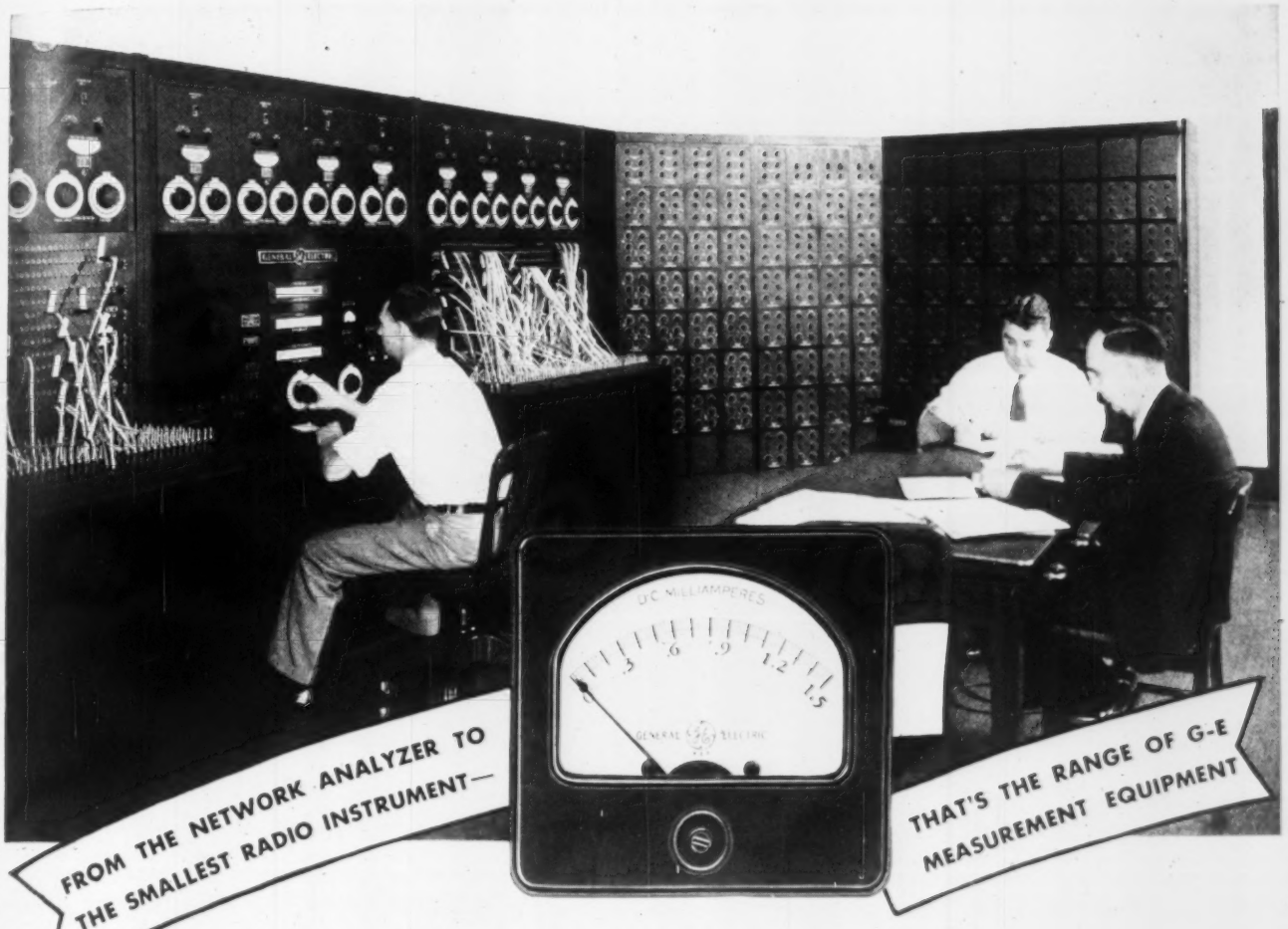

WITH the G-E network analyzer you can represent the lines, equipment, and power conditions of the largest utility company and make calculations involving an entire power system. You can determine how your system can best take on new factory loads. You can even find out what will happen to breakers at Substation B when there's a short circuit on Feeder 15.

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That is why General Electric is better able to solve your problems involving the measurement of any quantity. That is why, as a leading designer and manufacturer of electric instruments for almost 50 years, General Electric is known as . . . . . .

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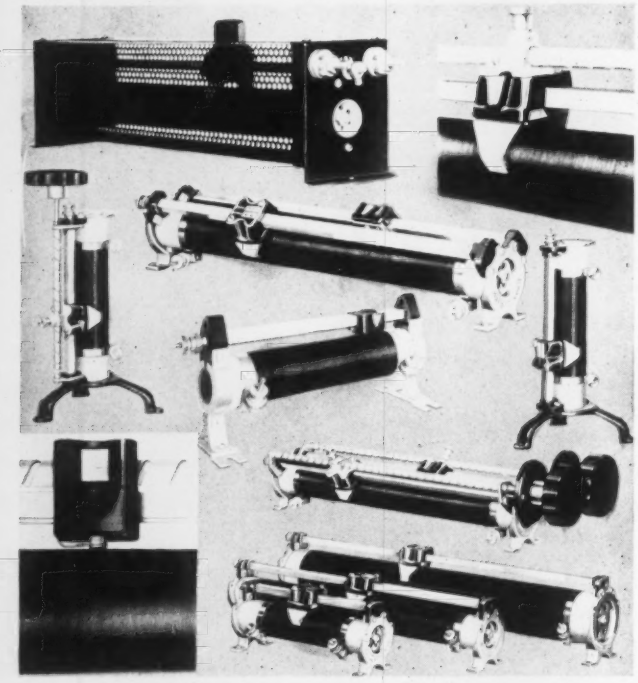

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Instruments

THE MAGAZINE OF MEASUREMENT and CONTROL

VOL. 11 No. 9

SEPTEMBER, 1938

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INSTRUMENTS The Magazine of MEASUREMENT and CONTROL

M. F. BEHAR
EDITOR

IN THIS ISSUE

Power Superintendent Dulmage concludes his series of five articles on the instrumentation of Ford Power Plant No. 1 at Dearborn. It is hoped that his articles will inspire more industrial bigwigs to adopt Ford methods, and it is certain that such adoption will benefit management, workers and the general public.

"Judge" Staples they call him, but his fascinating description of how to run a temperature test entitles him to be called "Team Captain" Staples.

The importance of elastic properties with regard to hardness measurements has long been suspected. Professor Williams begins a thorough discussion of this subject. Don't assume that you can skip it as too elementary for you!

NOT in this issue: Solutions and discussions of Instrumentation Forum Problem No. 20. Again a "judge" to whom we "passed the buck" finds it necessary to study closely the thirteen solutions and discussions before deciding which **he** will adopt. (Yes, the judge is the inquirer!)

THE FRONT COVER

shows the Main Switchboard which W. W. Dulmage describes in detail on pages 217-218.

"When's that electrical instrumentation book coming out?" many of you have asked. Some of you remind us sarcastically that when it began to appear serially, in 1934, a footnote promised that it would be issued in book form in 1936. Well, the serial ran until 1937 and . . . it hasn't concluded! The concluding chapters are always the toughest—especially when governmental, engineering and other bodies increase their demands on one's time—but with a distinguished expert like Perry Borden as collaborator, guide, mentor and source of inspiration, we'll try to ignore that there are only 168 hours in a week.

Open Letter to the President

Honorable Franklin D. Roosevelt
The White House
Washington, D. C.

Dear Mr. President:

Some commentators assert that you have had trouble getting facts and true pictures of situations (other than political), because most of the so-called experts who have been reporting to you don't tell you the truth or tell you only what they think you'd like to hear. It probably isn't as bad as all that. We Americans are outspoken and plain speaking and it is a reflection on our national character to imply that the officials and the hundreds of representatives of business, industry, science, education, agriculture, etc., who report to you are tricky rascals. Nevertheless, it would seem that in some instances where you have appointed eminent non-technical citizens to investigate complicated situations, and where these prominent men appointed subcommittees which in turn employed specialists, the summarized reports did not accurately represent the detailed body of data but expressed to a certain extent the preconceived notions of those who signed the reports. I believe that a case in point is:

Technological Trends and National Policy; Including the Social Implications of New Inventions. Report of the Subcommittee on Technology (W. F. OGBURN, J. C. MERRIAM, E. C. ELLIOTT) to the National Resources Committee. Government Printing Office, Washington, 1937. Paper, 9x11½ inches, x + 388 pages. Price $1.00.

which received a great deal of newspaper publicity a year ago. The publicity was given to the brief findings and recommendations of Messrs. Ogburn, Merriam and Elliott—who yearn for a planned technology, who want to control inventors and engineers—not to the enormous mass of data contained in the body of the book. Just a year ago, resenting this attack on wealth-creating technology, I declared in this column (1) that planning the advance of technology means hampering it; (2) that it would cripple industry to have new methods and new devices passed upon by *any* dictatorial board in Washington.

I have recently finished reading the entire book and I take the liberty of suggesting that you skip pages 1-66 which end with praise of totalitarianism and condemnation of capitalism; and that you read (or have an engineer of your acquaintance read and summarize for you) pages 67-388. I make bold to predict that you will reach the conclusion which this magazine has summed up in the slogan repeatedly printed on this page during the last few years: **"Automaticity MAKES Jobs!"**

Or else, Mr. President, call into your office the technical authorities who contributed to pages 67-388—especially Harrison Howe, David Weintraub, A. A. Potter, A. W. Cruse and others with technological experience.

Respectfully yours,

M. F. BEHAR, *Editor*

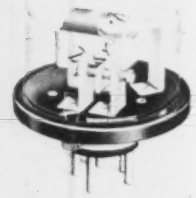
THE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Sensitive Relay



Supplementing maker's d.c. relay (see *Instruments*, August 1936, page 219) new Type 3-A is designed for electronic and delicate control applications. Silver contacts form an s.p.d.t. switch for non-inductive loads up to 150 watts at 110 volts a.c. Relay requires 12 milli-watts for its operation; is available in various field resistances; has individual adjustments for hairspring tension, contact spacing, and armature gap; is housed in a dust-proof metal case 2¾" diam. × 2½" high finished in black. Standard 5-prong base permits plug-in mounting with simultaneous electrical and mechanical connection, thus facilitating revision or extension of control panels. *Sigma Instruments, Inc., 88 Trapelo Road, Belmont, Mass.*

U-v. Light Source

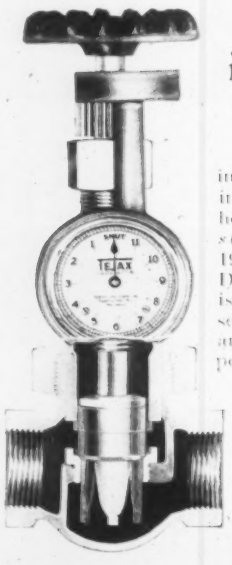
New 100-watt high-intensity mercury-vapor lamp has outer bulb of dense purple glass which transmits the near-ultra-violet radiation but is almost completely opaque to visible light; only a faint purple glow being visible when lamp is burning. Electrical characteristics being the same as those of the 100-watt illumination type high-intensity mercury-vapor lamp, it is used with the same transformer. Rated life is 1000 hours. *Lamp Div., Westinghouse Elec. & Mfg. Co., Bloomfield, N. J.*

Tube Tester

New "Dynoptimum" is said to test all latest as well as old tubes including cold-cathode rectifiers, metal and MG spray shield. Functions include tests for hot inter-element shorts and leakages, hot cathode leakage, sectional defects of full-wave rectifiers, duo diodes and all multi-purpose tubes. Main instrument is a 3" d'Arsonval, 2% accuracy. There also is a line voltage indicator. *Radio City Products Co., 88 Park Place, New York City.*

Time-temperature Cycle Control

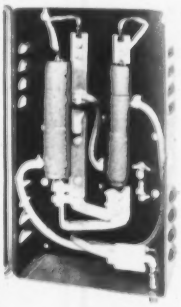
For applications where temperatures are desired to be varied according to a predetermined schedule "over any period of time," new Wheelco Program Control is said to permit "any desired temperature program" to be carried through without supervision. It consists of a Capacitrol temperature control unit (see *Instruments*, Nov. 1935, page 304) mounted integrally with a synchronous motor-clock driven cam type program unit. Each cam, or "program disk," is individually cut to the required contour. To the temperature-setting pointer of the Capacitrol is attached a follower riding on the rotating program disk, so that the temperature setting at any moment is governed by the follower. *Wheelco Instruments Co., 1853 S. Halsted St., Chicago, Ill.*



Position-indicating Valves

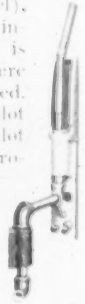
Supplementing indicator for valves installed with stem horizontal (see *Instruments*, Feb. 1935, page 52) new Dial Control Valve is a complete assembly of indicator and high-lift V-port valve. Available in bronze and steel bodies, trim of various alloys; sizes ½" to 2". *Tefft Jackson, Inc., 2 Allens Ave., Providence, R. I.*

Electronic Welding Contactor



For welding mild steel products and other readily-welded metals, new "Weldotrol" controls primary of welding transformers, is suitable for use with existing timing devices, functions as instantaneous power switch for producing uniform welds, has no moving parts or arcing contacts, is available in ratings roughly equivalent to 300 and 600 amp. conventional welding contactors, with either sealed-off or continuously pumped Ignitron tubes. *Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.*

Automatic Gas Pilot

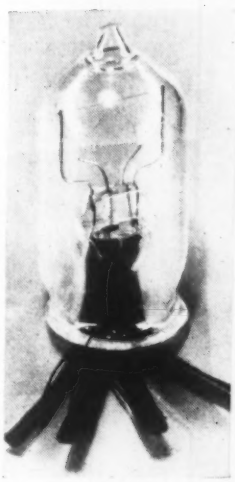


Thermal element of new automatic gas burner pilot is of unique design: it consists of two strips of the same material (heat-resisting Cr-Ni steel), one exposed to flame, the other insulated. Differential expansion is multiplied at end of lever where electric contacts are located. Among features claimed for pilot are: absolute reliability of pilot burner; efficient direction and protection of pilot flame so as to insure ignition of main burner even though gas pressure may be too low to close the electric pilot switch; safety feature whereby in event of pilot burner's going out for any reason main burner is automatically shut down and remains shut down until pilot burner has been relighted. *Julian P. Friez & Sons, Baltimore St. & Central Ave., Baltimore, Md.*

Industrial Capacitors

New "Type JDF" electrolytic capacitors for motor-starting and other applications are hermetically sealed in lock-seamed aluminum containers, are equipped with Bakelite terminal block having two dummy-screw terminals (arranged for convenient wiring to motor, line and thermostat, in refrigerator applications), are designed for operation involving a maximum of 20 starts per hour, each start of 3-sec. duration. *Cornell-Dubilier Electric Corp., South Plainfield, N. J.*

Vacuum . . . Thermocouples



Ranges from 1 milliampere to 10 amperes, in either contact or separate heater types. Prices from $3.00, quantity discounts.

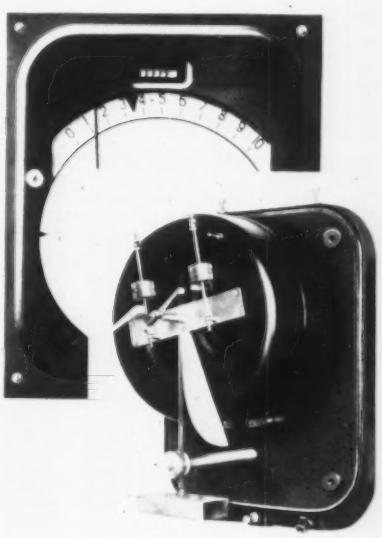
Write for Bulletin "A"

AMERICAN Electrical Sales Co. Inc.

67 E. 8th St. New York, N. Y.

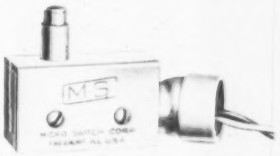
Ring-balance Flowmeter

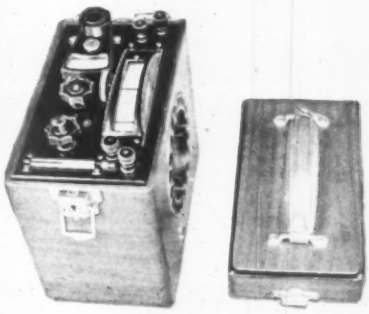
Particularly suitable for metering gases at pressures too low for mercury-and-float U-tubes, this new indicator-recorder-integrator is designed for differentials as low as 2" water. Its manometer is of the tilting-ring type (see schematic diagram) partly filled with water, oil or an anti-freeze liquid, and provided with a weight-and-cam square-root extractor (see back view) whereby charts and indicator scale are graduated uniformly in flow-rate units. As actually constructed, meter is said to be characterized by "exceptionally high-operating power for low-pressure gas measurement." Integrator is direct-reading. Accuracy (quickly checked by a calibrating weight) is guaranteed by maker. *Cochrane Corp., 17 N. 17th St., Philadelphia, Pa.*



Metal-clad Micro Switch

New Series Q metal-clad Micro Switch, with an overtravel of 1/32", has a 5/16" diam. plunger which can be moved 1/32" beyond operating point without straining snap-action mechanism, changing characteristics or affecting its life of "millions of operations." Mechanical operating requirements: 0.015" pretravel with operating pressure of 7.8 oz. and movement differential of 0.0002"-0.0003". Contact arrangements: normally closed, normally opened, or double-throw. Listed by Underwriters' Laboratories for 10 amps. 125 volts a.c.-2 amps. 600 volts a.c.-½ hp. motors 115-460 volts a.c. Metal housing, 2¾" × 1" × 3¼", available with right or left hand angle conduit fitting or with ½" straight fitting. Switch is especially suitable for service on automatic machinery. *Micro Switch Corp., 15 E. Spring St., Freeport, Ill.*





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- Hand drawn millivolt scales, or temperature scales in Fahrenheit, Centigrade, or both.
- Accuracy and sensitivity is far higher than any temperature calibrated pyrometer.
- Made in four different models, having special equipment for different classes of service work.
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A complete description is contained in our Catalogue V-B-V, which will gladly be furnished on request.

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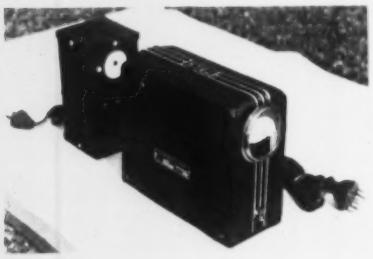
Fluorescent Tube Lighting Fixture

New Model FL-321 fluorescent tube fixture for color examination and general inspection work utilizes three 24" "Daylight" mercury discharge tubes with inside fluorescent coating converting ultra violet radiation of mercury arc into illumination closely approaching average daylight, hence excellent for color grading. Fixtures can also be supplied with white fluorescent tubes which provide a light approaching that of regular incandescent lamps. Unit measures 28" × 11 7/8" × 4 1/4", operates on single-phase 110 volt 60 cycle supply or on 3-phase 220 volt 60 cycle supply, consumes 80 watts, produces 1920 lumens. *Barkan Frink Tube Lighting Corp., 50-50 Bridge Plaza S., Long Island City, N. Y.*

Photoelectric Relay

Designed for industrial applications such as positioning of wrappers, machine safety guards, etc., where space is limited, new Model HR-3 Industrial Relay is housed in a 3" wide case. Other dimensions 7" × 6 1/2". Relay has two adjustments beside a lamp rheostat con-



trolling light intensity, is provided with an indicator so that effect of a changing light can be registered and relay set at a definite point. Light source illustrated consists of a 110 volt transformer operating a 6.8 volt concentrated-filament lamp with adjustable aperture. *Ess Instrument Co., 30 Irving Place, New York City.*

Electrostatic Voltmeter

Available in ratings of 3, 5, 10, 15 and 20 kv., a portable electrostatic voltmeter for measurements of a.c. or d.c. voltage on systems where one line is grounded, has a light-beam pointer, magnetic damping, and a specially designed high-voltage terminal with a current-limiting resistor for increased safety. Accuracy of 2% of full-scale value is maintained in all ratings, when used on a.c. up to 500 cycles,

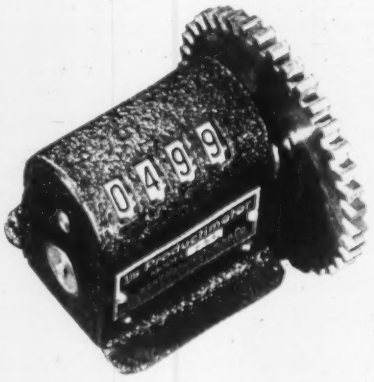
NEW Universal HAND TACHOMETER

"Jagabi" Type A Universal Hand Tachometer

Measures any speed from 50 to 40,000 r.p.m. (25 to 50,000 r.p.m. also available).
Only three ranges. Pointer turns twice around dial.
Equivalent to a six-range tachometer.
Operates on centrifugal principle.
Direct-reading. Accurate. Dead beat.
New mechanical features.

Write for Bulletin 1575-I and prices.

JAMES G. BIDDLE CO.
ELECTRICAL INSTRUMENTS
1211-13 ARCH STREET PHILADELPHIA, PA.



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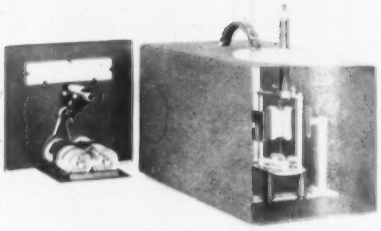
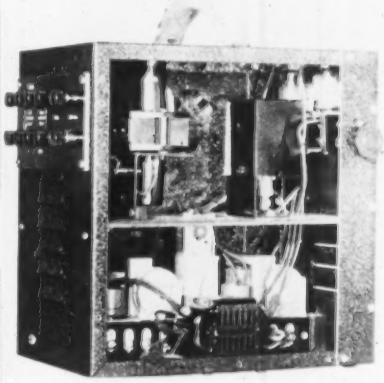


or d.c. Responsiveness is approx. 1 sec. Target appears on scale as a bright line that can be seen under all conditions of external illumination. Instruments are shipped from the factory completely assembled and calibrated. Calibration is not disturbed when unit is moved from one location to another. To place instrument in operation, ground case, energize light source, and make high-voltage connections. Grounded aluminum case provides effective shielding against stray electrostatic fields. Terminal is insulated by a transparent plate permitting ready inspection. *General Electric Co., Schenectady, N. Y.*

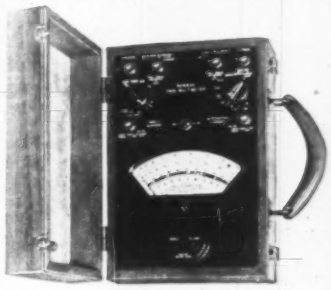
Contact-making Galvanometer

For permanent or temporary installations in factory or laboratory, for use with bridges or other apparatus requiring an external galvanometer, new portable photoelectric contact-making galvanometer actuates control circuits or alarms, operates from 60-cycle supply as follows: Galvanometer mirror reflects a light beam upon a scale where two adjustable phototubes, one controlling a high and



the other a low contact, intercept the beam for any desired values pre-set by external knobs and indicated by pointers. Each phototube actuates an electronic relay equipped with an s.p.d.t. contact. The contacts are rated 1 amp., 115 volts for non-reactive circuits. Sensitivity of 22 microvolts per division being obtainable, instrument can be used for temperature measurement and control with thermocouples, radiation receivers and other weak-output primary elements; in bridge circuits for measurement of resistance; for production testing of resistors and bar-to-bar testing of large electrical machinery; in circuits for measurement and control of light, viscosity or pH; and for mercury-vapor or ion detection. *General Electric Co., Schenectady, N. Y.*

Rawson Twin Multimeter



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20 microvolts to 1000 volts
A.C. cps to 3000 cycles
2 milliamperes to 3 amperes
60 millivolts to 1000 volts

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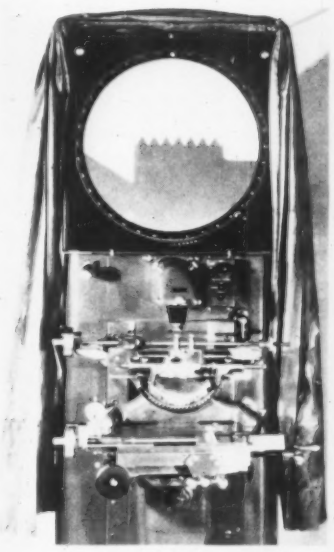
Representative: E. N. Webber
1313 W. Randolph St., Chicago, Ill.

Contour Measuring Projector

Main feature of this large (6 ft. high) contour measuring projector is a new optical system whereby images have a far higher degree of geometrical accuracy, dimensional accuracy, brightness



and edge sharpness than those formed by any projector heretofore produced. Performance of projection lenses approaches limits set by basic laws of optics. With magnification of 10×, measurements can be made more accurately than is possible with older types operating at 25×. Screen size is 18". Focusing is electric drive. Magnifications available range from 10× to 100×. Cross-slide table and measuring accessories permit 6" of right and left motion and 1" of back and front motion, both to 0.00001". *Bausch & Lomb Optical Co., 635 St. Paul St., Rochester, N. Y.*

Micrometer-comparator

In new Indicating Micrometer and Comparator, all gears and racks have been eliminated from indicator mechanism: knife-edge lever type is used in-

stead, making instrument more durable. Anvil relieving button and a light pressure return spring eliminate personal equation since "measuring feel" does not enter into readings. Tungsten carbide alloy anvil faces are said to give 40 times longer wear than hardened steel, are polished plane and parallel to optical flats accurate to 0.000012". Instrument is constructed for use in machine shop and in quantity production. *George Scherr Co., 120 Lafayette St., New York City.*

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FOR BOTTLED GAS AND OTHER LIQUEFIED GAS PRODUCTS

The moisture content of gas passing through the Tester is shown by the color of indicating cartridge.

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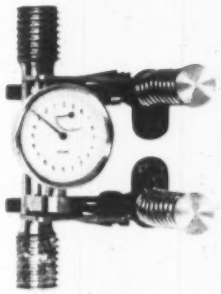

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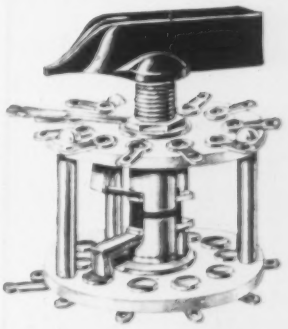

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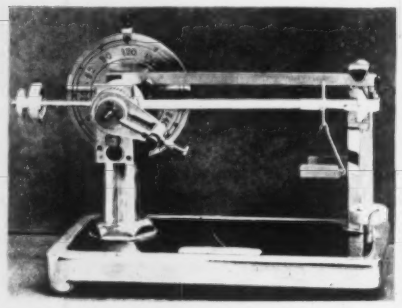

tester is designed and constructed for production routine, is said to be capable of withstanding years of such service. Operation: outer end of spring is set to maintain unloaded beam at zero; dial is turned to selected angle; precision weights are added until beam again stops at equilibrium point. For routine work, single standardized weights are used. *The R. Y. Ferner Co., 131 State St., Boston, Mass.*

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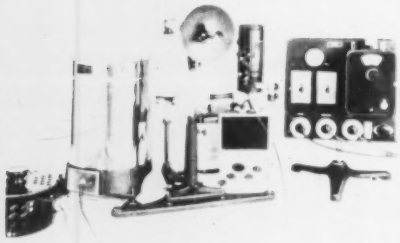

able or panel L&N potentiometers, portable ammeter, specimen tool set, bath and automatic temperature control, etc. Illustration shows Dilatation Interferometer Equipment for accurate determinations on metals, alloys, ceramic materials, glasses, enamels, etc. Interferometer is highly refined Fabry & Perot type. Viewing apparatus has prism reflecting light along its vertical axis and thus may be rotated between different furnaces and test table without discontinuity. *Gaertner Scientific Co., 1211 Wrightwood Ave., Chicago, Ill.*

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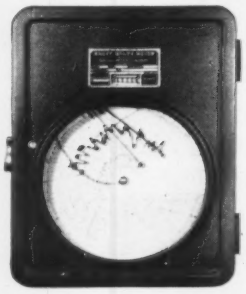

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● This dependable and accurate guide to maximum combustion economy is easily understood and followed by operators. It indicates, records and integrates Steam Flow from the boiler, records Air Flow supplied for combustion, and records Flue Gas Temperature.

Best combustion efficiency is secured by keeping Steam Flow and Air Flow pens together so that the records coincide one upon the other. The record of flue gas temperature when compared with that of Steam Flow shows the condition of baffles and tubes, and indicates heat absorption efficiency.

The Bailey Steam Flow-Air Flow Boiler Meter reduces fuel costs, lessens maintenance and outage, lowers standby costs and adds capacity. It is suitable for boiler plants operating units of 100 h.p. or more fired with stokers, pulverized coal, gas, oil or other fuels.

In order to obtain the maximum benefit from the Bailey Boiler Meter, it should be made an integral part of a Bailey Combustion Control System so that combustion losses are automatically corrected for even as they tend to appear.

For further details, refer to Sweet's Engineering Catalog or send for a copy of bulletin No. 46.

BAILEY METER COMPANY
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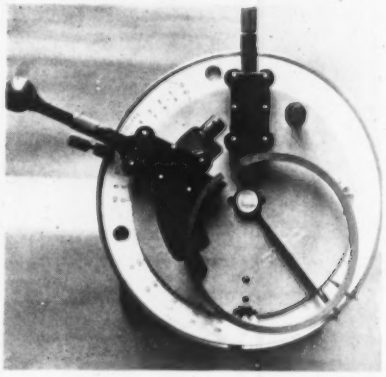
Bailey Meter Company Ltd., Montreal, Canada

Wilson scheme of compensation, [illegible] desirable characteristics. Accuracy conforms to highest NEMA ratings, [illegible] $^1/_4Y$ and $^1/_4Z$ at 60 cycles. On [illegible] voltages, with a $1.5 \times 40\mu$ sec. wave, strength = 2.2" test gap. Standard factory test of unit is 19 kv. at 60 [illegible]. Mechanical overcurrent rating [illegible] and thermal is 70×, rated current for one second. *General Electric Co., Schenectady, N. Y.*

Piston-ring Tester

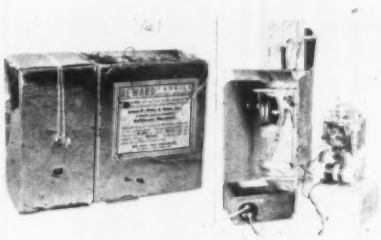
Entirely new method developed by A. A. Ansler in Switzerland is employed in new "Type K337" tester said to be the first in which the ring is closed or opened



by virtue of constant bending moment distributed over entire circumference, and in which friction effects are negligible. Different measuring ranges are provided for different piston sizes. Tester can be calibrated quickly and "irrefutably." A ring can be tested to fracture point and then its broken parts can be tested individually in either direction. Tolerance-limit gages are provided for routine testing of quantity lots. *Herman A. Holz, 167 E. 92nd St., New York City.*

Radio Meteorograph

U. S. Weather Bureau's new program of extensive research into stratosphere weather is based on free-balloon radio transmitters. Balloons eventually burst;



instruments float to earth on parachutes; finders are rewarded. Illustration shows (*a*) appearance of transmitter package bearing instructions for obtaining reward; (*b*) parts of transmitter, showing instruments for measuring air pressure, temperature and relative humidity, and equipment which translates instrument readings into r-f. signals. *Julien P. Friez & Sons, Baltimore St. and Central Ave., Baltimore, Md.*

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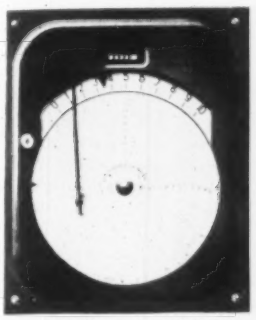
Distinguished for extreme accuracy and high quality, Cochrane Flow Meters are reliable guides for controlling rate of consumption, make, output or variation in the rate of flow of steam, gases, water and other liquids. The Electric Model utilizes the galvanometer null principle.



ELECTRICAL MODEL

MECHANICAL MODEL

The sensitive galvanometer detects the slightest change in rate of fluid flow, unaffected by friction or variations in voltage or frequency. Can be installed any distance from pipe line. The mechanical model develops an extremely high torque, is accurate in design, simple and rugged in construction.

ORIFICE METERS AND TYPE E WEIR METERS

—have the same Cochrane accuracy and simplicity and are highly regarded by users for their particular applications.

Write for Publication Nos. 2092, 2094, 2096

COCHRANE CORPORATION
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FLOW METERS

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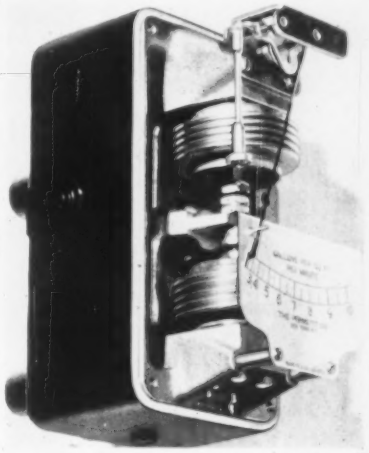
HAYS Portable Combustion Test Sets are in high favor with traveling engineers. The one shown above includes a 3-unit gas analyzer (CO_2, O_2 and CO), a metal armored flue gas thermometer and a Dry Type Draft Gage. Each unit may be used independently of the others. The Hays is known as the "world's fastest Orsat" —complete analysis within 3 to 4 minutes. Extremely accurate, sturdy in construction, compact in size. Many other types available. Send for Catalog 38-323. Write Dept. 11-9-8.

The HAYS CORPORATION
COMBUSTION ENGINEERS AND CONTRACTORS
MICHIGAN CITY, INDIANA, U.S.A.

Flow-rate Indicator

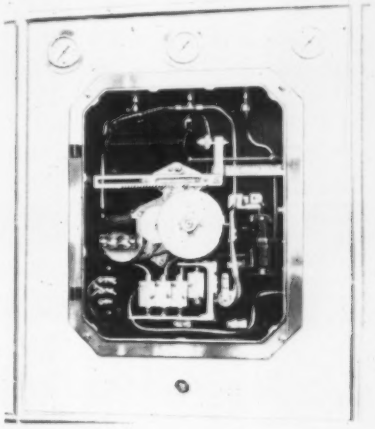
Electric contact, for signal or automatic control purposes, is optional equipment on new Permutit Rate of Flow Indicator (illustrated with cover removed).



Essentially it is a differential manometer for use with an orifice plate or other primary element in pipe line. Responsive element is a pair of metallic bellows with outer ends rigidly attached to brass body and inner ends to transmitting rod of magnifying linkage. Two air traps, formed in the brass body itself, prevent liquid reaching bellows and act as sediment chambers. Available models include one with a zero-center scale, indicating direction as well as rate, for softeners, filters, etc. *The Permutit Co., 330 W. 42nd St., New York City.*

Time-cycle Controller "Bumping" Feature

Automatic "bumping" of platen presses (slightly opening several times at beginning or near end of curing cycle) to release entrapped air or gas, is accomplished with a new feature of maker's adjustable (illustrated) or fixed-cam pneumatic time-cycle controllers. Bumping operation is independent of both time and press-ram travel, takes place only when ram pressure has built up to a predetermined value sufficient to drive entrapped air or gas to surface of product where it can escape when press is "cracked." *Taylor Instrument Companies, 95 Ames St., Rochester, N. Y.*



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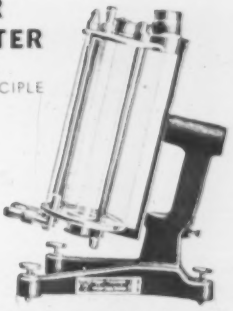

Model B

For determining the ABSOLUTE viscosity of paints, oils, lacquers, varnishes, varnish gums, resins, etc. Direct reading in Centipoises (or centistokes). Small sample (30 cc.) required. Results consistent and reproducible. Difference in viscosity between distilled and tap water can be measured.

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We also make galvanometers, electrometers, colorimeters, permeameters, Wheatstone and Kelvin Bridges, Resistance standards, coil testers, acronographs, clip-on transformer ammeters.

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RUBICON COMPANY
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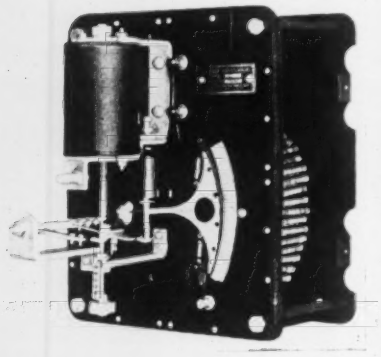
29 North 6th Street Philadelphia, Pa.

A-c. or D-c. Generator Voltage Regulator

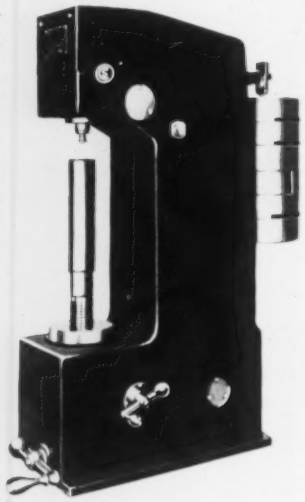
Designed for automatic voltage control of small a-c. and d-c. generators, new "Type V-O" employs rocking-contact principle heretofore available only in larger, costlier regulators. (See *Instruments*, Feb. 1937, page 37) and acts as



quickly, regulating voltage by directly varying resistance in field circuit. Voltage-sensitive solenoid rocks a carbon-rimmed contact sector over inner surface of a commutator the segments of which are connected permanently to the regulating resistance. Segments are heavily silver plated to insure positive contact surface. There are no parts to replace or readjust at relatively frequent intervals. Two simple adjustments made at time of installation, all major adjustments being made at the factory. New regulator is suitable for either switchboard or wall mounting. *Switchgear Div., Allis-Chalmers Mfg. Co., Milwaukee, Wis.*

Deadweight Type Hardness Tester

Among features of new Model UK-300 Deadweight Brinell Testing Machine are two hand cranks for rapid operation: one at side for elevating screw and



one in front for applying or releasing load through worm and wheel. Machine can be supplied using a conventional Brinell microscope, or with direct-reading indicator. *Steel City Testing Labs., 8853 Livernois Ave., Detroit, Mich.*

CAPACITROL

Temperature Control Pyrometer

Operates on new Wheelco "Radio Principle." All electrical Control without cams, motors or mechanical parts. Its simple, rugged construction provides low cost—positive, instantaneous Control. With Wheelco Controllers it is possible to get BETTER Control than with ANY mechanically operated instrument.

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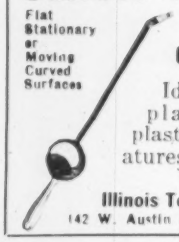

The "Alnor" Combination Pyrocon

Ideal for rolls, molds, plates, platens and plastic material temperatures.

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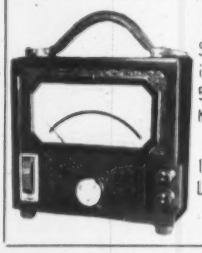
NEW "ALNOR" PORTABLE PYROMETER



Shock Resisting, Floating Movement, Has 5" Mirrored Scale Metal Case.

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ILLINOIS TESTING LABORATORIES, Inc.

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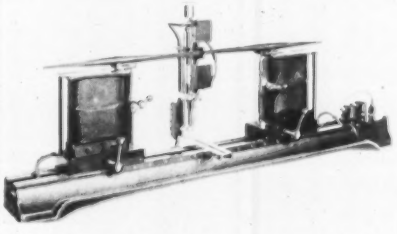
Combination Watthour Meter and Time Switch

New combination watthour meter and time switch makes possible economies in metering or controlling either two-rate or off-peak domestic loads. In the double-dial registers for two-rate applications, time switch controls drive to register

gear trains and operates off-peak contacts when used. In the single-dial registers for off-peak applications, time switch operates and controls off-peak contacts. Contacts may be s-p.s-t. or d-p.s-t., are clearly visible for inspection through side of glass cover. Complete mechanism is mounted on a supporting frame provided with standard register bayonets for mounting assembly on meter frame. Time switch is synchronous-motor-operated. A sealable-screw plug permits setting switch time without removing glass cover. *Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.*

Fatigue Tester

Entirely new, elaborate, "Rayflex" fatigue testing machine takes specimens $\frac{1}{4}$" to 1" diam. or thick, 1' to 3' long, flat stock to 5" wide, vibrates a specimen at its own frequency, specimen being supported at nodes. Load is applied



at ends by electromagnets actuated from an oscillator-amplifier (on panel, not illustrated). Frequency, 100-3000 cps., is controlled by specimen, so that power required is only that necessary to supply energy dissipated during stress cycle. Auxiliary instruments and controls include: cycle count, frequency measurement, operating temperature measurement and control, automatic amplitude control, automatic shut-off governed by increase in natural period when crack progresses, determination of Young's modulus, Magnaflux test, strobuscope attachment, stress determination by amplitude indication on panel instrument, optical method of changing amplitude, etc. *Baldwin-Southwark Corp., Passchall Station, Philadelphia, Pa.*

Fig. 1. First three Sections of Main Switchboard, Power Plant No. 1.

Fig. 2. Fourth Section. There is no "back-of-the-board."

Ford Power Plant Instrumentation

5—Electrical Instrumentation of No. 1 Power Plant

By W. W. DULMAGE
Power Dept., Ford Motor Co., Dearborn, Mich.

IN order to present a readable description of the electrical instrumentation in No. 1 Power Plant, we shall refrain from giving methodical tabulations as we did in the preceding articles. The reason is obvious: it is the great number and variety of electrical instruments, meters and telemetering systems; as well as of instrument like regulators, relays and other devices which embody electrical measuring elements and are therefore of interest to *Instruments* readers.

Without wishing to indulge in the sensational journalism style, I may mention that if the electrical instrumentation of No. 1 Power Plant had been delivered in one shipment, the cases, crates and cartons would have filled three standard freight cars—possibly four! Detailed inventories would fill several pages—which nobody would care to read. For the convenience of the readers, therefore, we shall simply divide all of our electrical instruments, meters, etc., into three obvious groupings:

(1) Those which are concentrated on the Main Switchboard.
(2) Those which are permanently installed elsewhere.
(3) The portable instruments, shunts, etc.

(1) MAIN SWITCHBOARD

This orderly array of electrical devices, and its appurtenances, corresponds fairly closly to the equipment of a Load Dispatcher's Department in the central station of a public utility. Its functions are similar in kind and degree: in kind, because load peaks and valleys must be handled with optimum economy combined with unfailing service to all "customers"; in degree, because the 345,000 kilowatt capacity of No. 1 Power Plant is more than sufficient to supply "juice" to a city of 50,000 modern electrified homes all fully equipped with radios, electric washing machines and other appliances.

The Main Switchboard consists of four separate and distinct boards. (The letters correspond to those on Fig. 1 and Fig. 2).

(A) *The Telephone Desk* whereby we can communicate with all main operating and power distribution points throughout the Power House and local Ford Plants. This is a magneto type telephone system and through this all parts of the system can be inter-connected.

(B) *The Control Desk:* The function of this board is to control exciters, generator voltage, frequency, load distribution and service to feeder circuits. Excitation is adjusted to maintain correct generator voltage at all times. Machine frequency and individual generator load distribution is maintained by the control of motor-operated governor on each machine, and service to Sub Stations through oil circuit breakers at 13800 volts. This board is laid out in mimic bus with control switches and indicating lights arranged to present to the operator an exact duplicate of actual installation.

It is worth noting the method of control exercised by the operators on the switchboard over generator loadings. The main operating governor of the turbines is of the centrifugal type, driven by the turbine shaft through a worm gear. It is provided with a d.c. motor-operated synchronizing device for controlling the speed from the switchboard while running and without otherwise disturbing the operation of the unit. The motor-operated synchronizing mechanism is adequate to maintain rated frequency at all loads under steam conditions specified for each engine.

Every function initiated on this control desk is indicated on the "meter section", next described.

(C) *The Indicating Meter Section:* This board provides an actual indication of generator, exciter and feeder circuit conditions. Ammeters in the field circuits indicate the current flow. Voltmeters indicate the excitation and generator voltage. Frequency meter indicates the system frequency. Because each 110,000 kw. generator is really four generators in one we indicate by ammeters, power factor meters, and kilowattmeters the electrical performance of each winding. These windings are connected in groups of two and carried to individual buses, where we again meter them as two generators.

Each feeder has an ammeter and kilowattmeter to indicate power and current flow over each circuit.

In our Main Switch-house there are six separate bus sections, and each section is metered to indicate the transfer of load and direction of flow.

(D) *Graphic Recorder, Integrating Meter and Relay Section:* This board provides a continuous record of excitation voltage, bus voltage, system frequency and kilowatt load on each generator. Each circuit is also provided with a kilowatthour meter. To record the generation and distribution of power a graphic recorder is connected with the windings of each generator to provide a record of station output at all times. Through Selsyn

motor control this is connected to an indicating meter for operating information. Relays are connected to generator circuits, bus sections and outgoing feeders to provide a continuous protection against electrical faults.

(2) PERMANENTLY INSTALLED ELSEWHERE

Many of the electrical instruments installed elsewhere than on the Main Switchboard have been described in the preceding articles and photographs have been taken showing them. They were included in the preceding articles because, though employing electric measurement principles, they serve non-electrical purposes. (Examples, conductivity type CO_2 recorders, calibrated resistor type flowmeters, thermoelectric typestemperature recorders, etc., pertaining to boilers, turbines, etc.) Some other electrical instrument boards were not described in preceding articles because they pertain to electrical equipment. Fig. 3 shows one of these. Its purpose is to provide continuous records of generator winding temperatures. In addition, alarms are installed to notify the operator of any unusual conditions. There are two such boards, located opposite the North and South ends of the Main Switchboard and only separated therefrom by glass partitions, so that they may be said to constitute additional "wings" of the Main Switchboard.

Fig. 3. One of the two generator temperature recorder and signal panels.

(3) PORTABLE ELECTRICAL INSTRUMENTATION

Testing and checking are the principal functions of our large assortment of portable instruments. For example, the previously described permanently-installed thermoelectric pyrometers are supplemented by portable thermoelectric pyrometers, some portables being used for occasional measurements at points not wired for recorders, and others being used for checking the permanently installed recorders. As a rule, a panel-board recorder is checked by means of a "precision portable" potentiometer. Many of the portable instruments, in turn, are checked by means of precision-grade laboratory potentiometers and bridges.

An inventory of miscellaneous portable instruments for non-electrical purposes would also bring out several types which are essentially electrical. For example, most optical pyrometers are of the disappearing-filament type where the temperature is read on a miniature milliammeter built into the device.

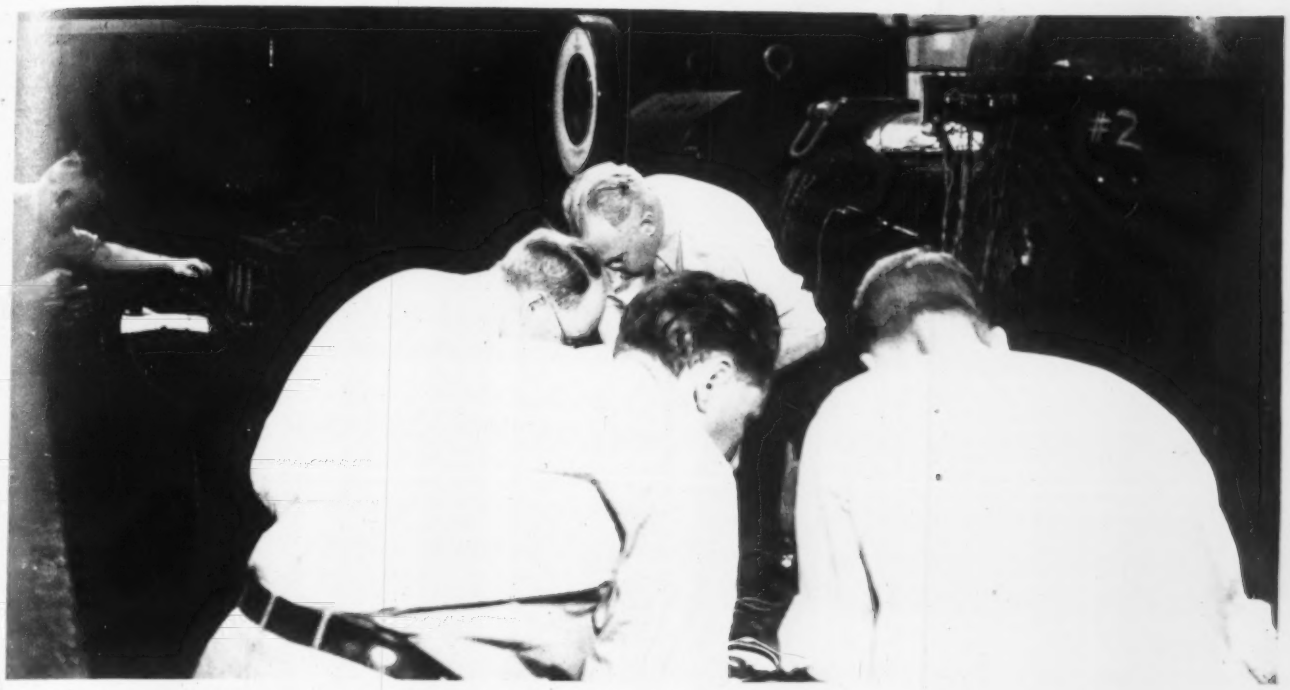
Mention must also be made of numerous general purpose portable electrical instruments such as ammeters with assortments of shunts, voltmeters with assortments of decade boxes, as well as self-contained multi-range voltmeters, wattmeters, ohmmeters, meggers, etc.

Fig. 4. Portable instruments find important uses in efficiency testing.

To go into descriptions of high-precision laboratory instruments would mean departing from our assigned subject of Power Plant Instrumentation. Suffice it to mention that the Ford Motor Co. has standardizing laboratories with facilities for calibrating our own Power Plant Standards.

CONCLUSION

ALTHOUGH we have some reason to be proud of the power plant instrumentation briefly described in these five articles, we do not wish to convey the impression that we are sitting back admiring our glittering instrument boards and turning our jobs over to miracle working mechanical and electrical brains. The careful reader will no doubt remember that every time we described an automatic-control system we mentioned that it is provided with a master knob which can be turned to "Manual". It is true that today there are small fully automatic gas-fired and oil-fired steam-heat systems for residences—even some coal-fired; but the day of "the manless plant" has not yet arrived in the field of 345,000-kw. steam power plants. Nevertheless it is equally true that without hundreds of accurate indicating instruments, a 345,000-kw. steam plant could not be operated at all; and it could not be operated *safely* and *economically* without hundreds of indicating, recording, integrating and automatic-control instruments supplemented by signal systems, telemetering systems, testing instruments and—trained instrument men.



Author is seen at extreme left in this "candid shot" of a temperature test.

Temperature Testing of a-c. single-phase COMMUTATOR Motors

By E. I. STAPLES

Laboratory Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

THE TEMPERATURE TEST, or heat run, is one of the most important to which all classes of electrical machines are subjected. Its purpose is to determine whether the apparatus will carry its specified load within a temperature limit fixed by the materials employed in its construction. While the procedure in temperature tests is governed by well-established test floor practice, it is felt that a review and discussion of the technique developed in our Railway Laboratory may be of interest.

Although we are not primarily interested here with the theory underlying temperature elevation in electrical machinery, some of the principles may be briefly stated as a preface for what we have to say later. The losses in the various parts of a dynamo-electric machine appear as heat. At the instant of application of load (assuming a previously idle machine) all surfaces are naturally at air temperature and, the temperature difference being zero, the rate of heat dissipation is also zero. At that instant, all of the heat produced is stored in the material of the motor, but this soon causes a rise in surface temperatures and a consequent dissipation of heat into the surrounding air. Assuming constant loss in the machine, the rate of temperature elevation immediately begins to decrease because part of the heat is now passing into the surrounding medium, leaving less to be stored. The rate of heat dissipation therefore constantly increases while the rate of temperature elevation constantly decreases. When the rate of heat dissipation equals the rate of heat production, the temperature becomes stationary and we have a steady-state condition corresponding to the ultimate temperature rise of the machine for a given load. The mathematical treatment of this effect has been the subject of a number of well-written papers and is not within the scope of this article.

SHUT-DOWN PROCEDURE IMPORTANT

The objective in temperature tests is to obtain the temperature rise in the various parts of a machine either at the end of some specified short time or at the end of a time sufficiently long for the ultimate rise to have been reached. In rotating machinery, particularly in a-c. commutator motors, it is not practicable to measure all temperatures of all parts while the machine is in operation. Hence, it is necessary to continue operation to the end of the specified time and then determine the temperatures at the instant of power removal by means of measurements taken *after* the motor has come to rest. It therefore is obvious that the value of the test depends on the correct performance of several operations *immediately* after the shutdown. All other matters are secondary to this. If the shutdown is not successfully consummated, the test is a failure. Comparison with the smooth split-second team-work of championship hockey or basketball suggests itself.

In far too many cases the personnel and equipment necessary for a successful shutdown are overlooked. Careful arrangements will be made for applying and controlling the load—only to find, when the time of shutdown arrives that incomplete facilities have been provided for taking the necessary data. In temperature tests of a-c. commutator motors the following data are usually obtained at shutdown:

(1) The resistance of the armature.

(2) The resistance of the compensating winding.

(3) The resistance of the interpole field winding.

(4) The resistance of the main or torque field winding.

(5) The temperature of the commutator by thermometer and thermocouple.

(6) The temperature of the surface of the armature iron in the air gap by thermocouple.

For a-c. commutator motors, the most successful method for measuring the resistances is to circulate a suitable direct current through the windings and measure the potentials across them with high-resistance millivoltmeters. Means of applying the circulating current immediately after the machine is stopped must be provided. The millivoltmeters should be connected to the various windings through switches so that they may be left clear of the power circuit during the run and then connected quickly at the shutdown. The armature potential is obtained by special points inserted through openings in the motor end housing.

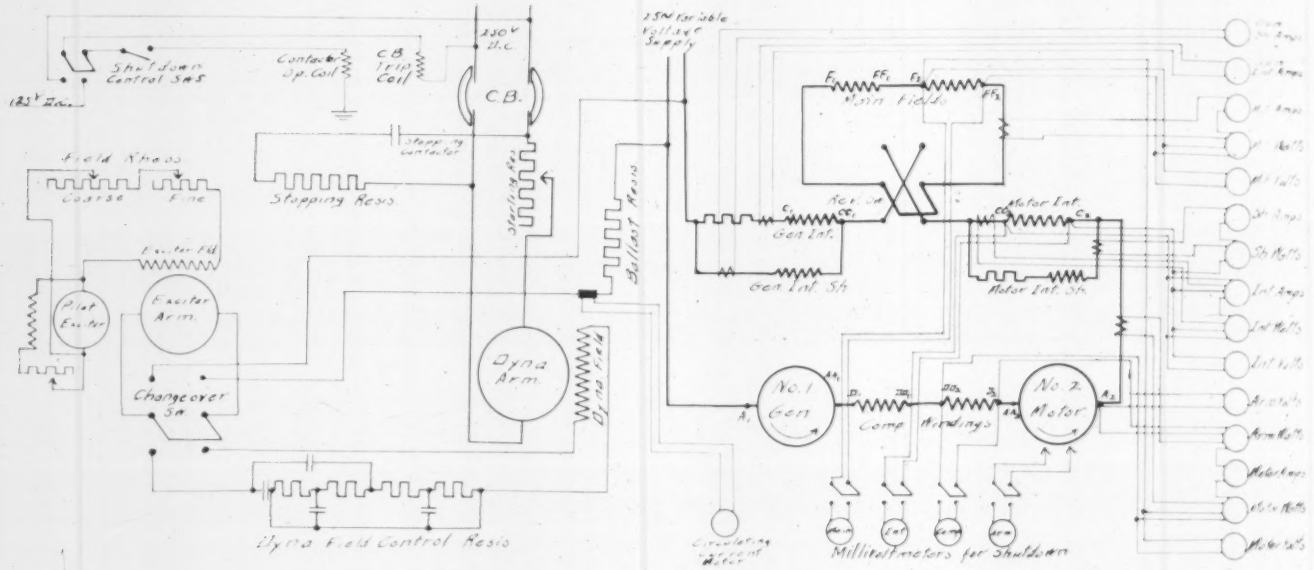


Fig. 1

A seven-man team is required for a successful shutdown. These men need not be outstandingly experienced. It is not difficult to make a shutdown when everyone knows what to do—and does it. In the Railway Laboratory we first make up written schedules (see example below). In this case, the athletic analogy that suggests itself is "skull practice"—but with the difference that after memorizing their duties our teams don't fumble when they get on the field.

Man "A" sees that all men are stationed at their respective places one minute before the time of shutdown. He blows a whistle at the instant he trips the power and starts the stop watch. Regularly, we take the first millivoltmeter readings forty-five seconds after the power is tripped; occasionally, after thirty seconds. More than a minute would be considered poor performance, indicating lack of preparation and co-ordination.

It is obvious that the test motor must be stopped quickly in order that the armature points may be applied quickly. This point is often overlooked. Unless there is some strong retarding action applied to the rotor of the test motor, it will come to rest in time to rotate far too long for the armature readings to be of any use whatever. Most of the temperature runs in the Railway Laboratory are made with the test motor coupled to a large dynamometer, which feeds its output into a resistance rack. When the power is removed from the test motor, retardation begins immediately but the rate of retardation also decreases as the dynamometer voltage falls off due to decreasing speed. The dynamometer control equipment includes a controller for operating a set of contactors which vary the resistance in series with the dynamometer field. As soon as the power is tripped, Man "A" notches up this controller and the resulting increase in dynamometer field strength quickly brings the machine to rest. In one particular series of tests (described more in detail below) the dynamometer was used as a driving motor to supply the rotational losses of two machines, which were loaded against each other. In this case a special changeover was provided in the dynamometer supply line whereby it could be quickly loaded into a resistor and the machines quickly stopped dynamically. This matter of stopping the test motor quickly is quite obvious, but easily overlooked.

Man	Duty
A	Trip power circuit, open transformer secondary switches, close switch for circulating current, start stop watch at time of tripping power, give signals to meter readers, hold circulating current constant.
B	Open interpole shunt circuit, apply armature points, read interpole millivoltmeter.
C	Hold flashlight for "B", read compensating millivoltmeter.
D	Trip blower, close damper in air duct, read interpole millivoltmeter.
E	Read main field millivoltmeter.
F	Read potentiometer on air gap and commutator thermocouples.
G	Apply air gap and commutator thermocouples, apply and read commutator thermometers.

TEMPERATURE TESTS OF THE 427 RAILWAY MOTOR

To bring out useful points, reference will now be made to a recent comprehensive series of temperature tests on the No. 427 Railway Motor. This motor is of the twin, single-phase commutator type and has a rating of 750 h.p. for the twin motor. While the horsepower capacity of the laboratory dynamometer would be adequate to load the twin motor, its torque rating is considerably too low to handle the output of the double motor when driving through gear reduction to the jack shaft and thence to the dynamometer. On the other hand, if a single motor of the twin were coupled direct to the dynamometer, the other motor being idle, the heat distribution in the motor, as a whole, would not be normal. It was decided to load one motor against the other, through the gearing, and couple the dynamometer to the jackshaft. In this way, both machines of the twin motor are normally loaded and the dynamometer merely acts as a d.c. driving motor to supply rotational losses. There was no particular reason for selecting the dynamometer for this drive, except that it was located conveniently and other tests involving its use as a dynamometer, with the same twin test motor, were contemplated.

The diagram of connections of both the test motor and the driving motor, with its exciter, is shown in Fig. 1. Since the two armatures are rotating in the same direction and carry the same current, if one is reversed with respect to the other, it will become a generator. The

compensating and interpole windings must also be reversed in order that they may perform their functions properly. Since the main or torque field of the generator is now reversed with respect to its armature, the component of interpole current, which is necessary to neutralize the transformer current in the short-circuited armature coils, must also be reversed. This requires an interpole shunt current lagging rather than leading the interpole current and, to obtain this, resistance is added in series with the interpole while reactance only is used in the shunt. The circuit as a whole is the same as that used in feed-back connections generally. The voltage across the motor is obtained from DD_2 to F_2 with the reversing switch down and counter-clockwise rotation.

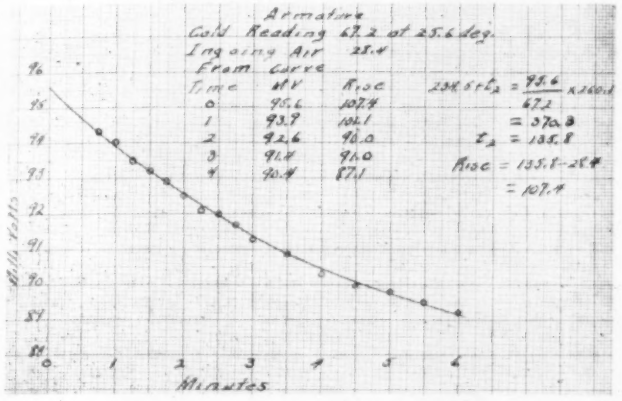


Fig. 2

With the reversing switch up and clockwise rotation, the motor voltage cannot be read directly. Throwing the reversing switch and not reversing the driving motor interchanges motor and generator. The only instruments necessary in the generator circuit are the ammeters in the interpole and interpole shunt circuit for obtaining the correct distribution of current in those circuits.

The dynamometer and its associated equipment are permanent equipment in the laboratory, most of the connections shown in the left-hand part of the diagram not being test connections. The shutdown control switches in the upper left-hand corner are so arranged that the stopping resistors can be connected across the 250-volt supply line only after the breaker has been tripped.

CALCULATION OF SHUTDOWN TEMPERATURES

The determination of the temperature rise at the instant of shutdown involves the calculation of the resistance of the various windings at that time and from the values of resistance the temperature can be calculated by the well-known law of resistance variation with temperature. In practice it is not necessary to use actual resistance values because, if the millivolt drops at shutdown and when cold are measured with the same instruments and with identical circulating current, the readings appear only as ratios in the calculation and can be used as read. The readings are plotted against time and the curve extrapolated back to time zero. Obviously, the accuracy of the method involves obtaining the first reading in a minimum time. A sample curve and calculation is shown in Fig. 2. This curve covers the armature from one of the tests described above. While the rise at time zero is the desired result, it is good practice to record the rise for several other times as well. The curves and calculations for all parts of the motor can usually be placed on one curve sheet.

The calculation involves the millivolt drop at some known temperature. The best way to obtain this is to let the motor stand overnight with the blower running. Readings should not be taken immediately after the blower is stopped because there may be a small temperature gradient through the motor due to the blower air being cooler or warmer than room air or due to its being slightly heated by friction within the motor. A thermometer placed in the commutator will, after an interval of half to three-quarters of an hour, give the motor temperature with satisfactory accuracy. Care should be taken in getting correct cold readings, as the accuracy of the results depends on proper cold values as well as proper hot readings.

The rises by resistance of the various parts of the motor are the most important results obtained from the temperature test. As check information, temperatures of the commutator surface are taken by thermometer and thermocouple, and the temperature of the armature iron is obtained by a special bayonet type thermocouple inserted in the air gap.

An approximate method of determining the armature temperatures is to take millivolt drops at a known temperature for a number of different commutator bars between points. These readings, when plotted against the number of bars spanned, will give a straight line. Knowing the number of bars between brushes, it always is possible to note quickly the bars spanned by the points and then, by reference to the curve of drop against bars, the rise can be calculated immediately without waiting until the next morning for cold readings. This method is sometimes necessary when taking a shut-down at the end of a short run to be followed immediately by another run. The regular method of leaving the points in place overnight is preferred and recommended whenever possible.

AIR MEASUREMENT

It is obviously essential that the ventilation of the motor be kept at its normal value at all times during the test. The rate of airflow in ducts for ventilating motors has been measured for many years by means of the electric air meter, which is a thoroughly reliable device when properly used. To avoid turbulence errors it is considered good practice to allow a straight length of pipe each side of the meter equal to ten times the duct diameter. The air system should be made as tight as possible on the motor side of the meter, otherwise the meter will not correctly give the volume of air going through the motor.

The effect of small leaks has sometimes been overlooked. The static pressure in the inlet chamber of the motor gives a definite measure of the amount of air going through the motor regardless of leaks in the duct system. It has become our practice to establish the ventilation upon this basis rather than upon air meter readings. The relation between static pressure and volume of air through the motor can be determined by means of an absolutely tight duct system or by closing up the air outlets of the motor and taking pressure volume data under this condition when all air is leakage. In test motors the structural details may not always be complete, in which case it is not easy to make the housing air tight. A number of small leaks will have a considerable percentage effect on the volume of air going through the motor.

The purpose of this discussion is to emphasize the need for accuracy and deliberation in taking temperature tests. The quickest way to make such a test is the most deliberate way. By reducing the procedure to a routine, it is possible to secure surprisingly consistent results. In the series of tests on the 427 motor, it was necessary to take thirty-three temperature runs to cover the entire range of speed and current. Practically all of the measured temperature rises fell into their proper places in the family of curves covering the range of loading.

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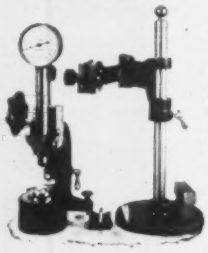

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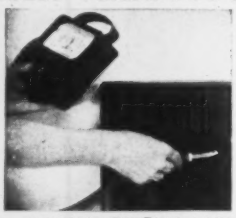

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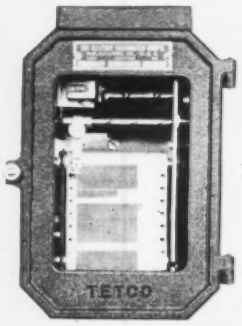

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Elastic Properties as a measure of Hardness

By S. R. WILLIAMS
Professor of Physics, Amherst College

THEORY

Among the various definitions of hardness, the one which states that hardness is the resistance to permanent deformation implies a definite relation between hardness and the elastic properties of a body, particularly the elastic limits of a body. In Fig. 26, April 1937 article, it was shown that the Brinell numbers were directly proportional to the tensile strengths of a series of carbon and alloy steels. This simple relation does not hold for all materials because other factors, such as creep, enter the picture. It was natural, therefore, that many attempts would be made to work out these relations in a practical method and employ the method for hardness testing.

There are two distinct kinds of elasticity: (*a*) elasticity of volume and (*b*) elasticity of form.

(*a*) A substance possesses volume elasticity if it tends to return to its original volume after being compressed by the application of a pressure, *i. e.*, the atoms, molecules or particles composing the body tend to maintain fixed distances between one another and resist any attempt to increase or decrease these distances. Compressing a gas or a liquid is an illustration of this type of elasticity. Change in volume of solids may be produced by applying hydrostatic pressure to the body. This produces uniform pressure all over and normal to the surface of the body.

(*b*) A substance has elasticity of form, or of rigidity, if the atoms, molecules or particles composing the body tend to maintain a fixed configuration, and resist any attempt to produce a slipping motion between these constituent particles. Thus, if a large book like a dictionary is twisted or sheared, so that the pages slide over each other, as in Fig. 163b, it is spoken of as a form distortion. Twisting a rod or wire does the same thing to the particles composing the rod or wire. See Fig. 164. In general, the elasticity of a body is the ability of that body to recover its original form or shape after having been distorted. Popularly, rubber is thought of as being an exceptionally elastic body. The degree of elasticity of a body is measured by its ability to return to its former shape once it has been distorted. Rubber is notoriously bad about returning completely to its previous condition.

In either of the two kinds of elasticity, a substance is said to be perfectly elastic if it always requires the same force to produce the same displacement. Thus a gas shows perfect volume elasticity at constant temperature. Within limits, called the "elastic limits," most bodies approach perfect elasticity. This is not absolute, however, as will be shown later on.

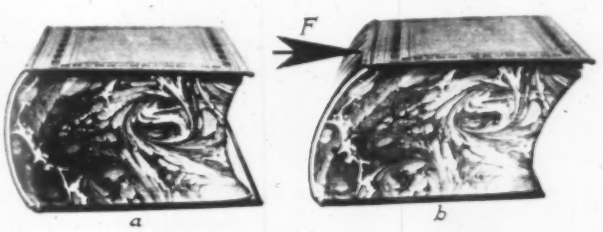

Fig. 163. By applying a force F to the upper cover of the dictionary the form of the book is changed from *a* to *b*.

HOOKE'S LAW

In 1676 Hooke announced a law concerning the relations between the displacements or distortions produced and the force producing that rearrangement of the particles in the substance. As a formula, Hooke's law may be stated in the following equation:

$$\frac{\text{Stress}}{\text{Strain}} = \text{a constant, within elastic limits.}$$

The greater the stress necessary to call forth a given strain, the greater will be the elasticity of the body. This law propounded by Hooke is applicable to both kinds of elasticity, volume and form, and in each case the constant becomes either the modulus of volume elasticity or the modulus of form elasticity.

(*a*) The modulus of volume elasticity is frequently referred to as the bulk modulus or the volume modulus. It is that constant in Hooke's law which gives the value of the ratio between the stress and the strain in a volume distortion. This modulus measures the ratio between the pressure which changes the distances between the particles and the resulting change in volume per unit volume. The change is a volume change. If the substance is a cubic crystal it remains a cube during the distortion. No change in form occurs. The restoring force (within elastic limits) called forth by the particles seeking to gain their former distances apart is just equal and oppositely directed to the external force which called the distortion into being.

Hooke's law, when applied to volume elasticity, becomes:

$$\frac{\text{Volume Stress}}{\text{Volume Strain}} = \text{Volume Modulus, (a constant)}$$

$$\frac{\dfrac{\text{Force}}{\text{Area}}}{\dfrac{\text{Change in Volume}}{\text{Volume}}} = k \qquad \frac{P}{\dfrac{v}{V}} = \frac{PV}{v}$$

where k is the volume or bulk modulus, P is the pressure, V the original volume and v the change in volume which occurred.

(*b*) The modulus of form elasticity is frequently referred to as the coefficient of rigidity, modulus of rigidity or the shearing modulus. It is that constant in Hooke's law which gives the value of the ratio between the shearing stress and the shearing strain, or the ratio between the force per unit area which gives rise to the shearing distortion and the angle of shear produced. Thus if a cubic crystal is sheared from a cube over into a form like that shown in Fig. 164a, it offers a resistance to this distortion. This restoring force is just equal to and oppositely directed to the external force which called forth the distortion. When a shearing stress is applied to a body, the constituent particles slide over each other and the form is changed. See Figs. 163 and 164. If n is the modulus of rigidity, an expression for the same may be obtained in the following theoretical way. Let a block *abcd a'b'c'd'*, Fig. 164a, be sheared to the right by a force F so that the original face whose edge is $a'c'$ moves

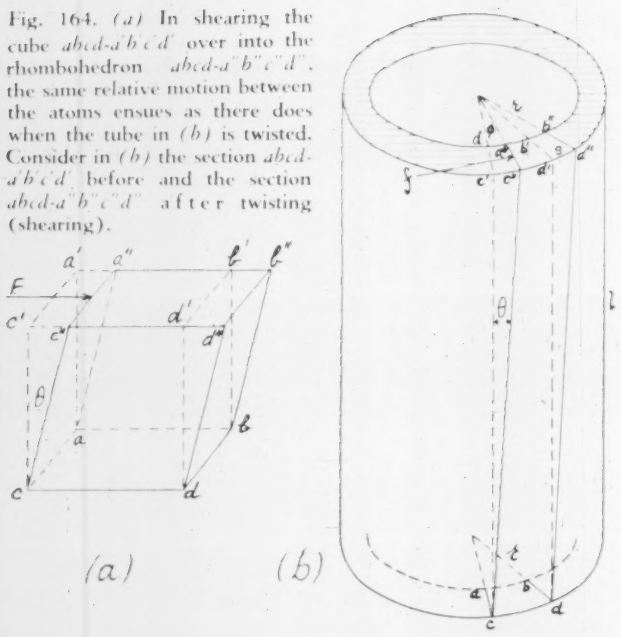

Fig. 164. *(a)* In shearing the cube *abcd-a'b'c'd'* over into the rhombohedron *abcd-a"b"c"d"*, the same relative motion between the atoms ensues as there does when the tube in *(b)* is twisted. Consider in *(b)* the section *abcd-a'b'c'd'* before and the section *abcd-a"b"c"d"* after twisting (shearing).

into the position *a"c"*. A counter force *F* must act on the bottom of the block, thus producing a couple. The particles of one layer of the block will resist sliding over the particles of an adjacent layer if elasticity of form is present.

Hooke's law, when applied to form elasticity, becomes:

$$\frac{\text{Shearing Stress}}{\text{Shearing Strain}} = \text{Rigidity Modulus (a constant)}$$

$$\frac{\text{Shearing force per unit area}}{\text{Displacement per unit distance between shearing surfaces}}$$

$$n = \frac{\text{Force}}{\text{Displacement}} \frac{\text{Area}}{\text{Distance}} = \frac{F}{s} \frac{A}{D} = \frac{F}{A\theta}$$

where A = area of surface sheared, s = distance it moves when $D = cc'$ = distance between layers, $s = D\theta$ for small angles.

In practice this is worked out by twisting rods through measured angles. Let *(b)*, Fig. 164, represent a thin walled tube, one end of which has been twisted through an angle ϕ radians with respect to the other end. Each small section *abcd* in *(b)* corresponds to the area *abcd* in *(a)*. When the tube is twisted, the layer *a'b'c'd'* is sheared around over adjacent layers just as *a'b'c'd'* was sheared over its neighboring layers in *(a)*. Let the total area of the end of the tube equal A, where *a'b'c'd'* is only a section of the same. If f is the force applied to the surface *a'b'c'd'* then $F = \Sigma f$, will be the total force applied to the surface A in twisting the tube through an angle ϕ. θ in *(b)* will have the same meaning as θ in *(a)*. In twisting the rod through an angle ϕ,

$$n = \frac{F}{A\theta}.$$

It is not easy to measure θ, but inasmuch as θ may be expressed in terms of ϕ, which is easily measured, it becomes an easy problem to measure n.

$$\frac{s}{l} = \theta \quad \text{and} \quad \frac{s}{r} = \phi, \quad \text{in Fig. 164.}$$

Hence,

$$\theta = \frac{\phi r}{l} \quad \text{and} \quad A = 2\pi rt,$$

where t is the thickness of the wall of the tube in r the average radius and l the length. Substituting these values in the last equation for n,

$$n = \frac{Fl}{2\pi r^2 t\phi}$$

The torque Fr applied to twisting the tube may be replaced by a small force acting at a greater arms length as shown in Fig. 165 where the force W is applied at an arm's length equal to the diameter of the wheel, h,

and $$Fr = Wh$$

or, $$F = \frac{Wh}{r}$$

The value of n may now be written,—

$$n = \frac{Whl}{2\pi r^3 t\phi} = \frac{mghl}{2\pi r^3 t\phi}$$

where $W = mg$, the weight of the mass m.

In the case of a solid rod it may be considered as a series of concentric tubes, to each one of which this last equation for n applies with its corresponding value of r. If one sums up the values of n for all of the tubes which comprise a solid rod one will obtain the value of n for the rod in which the radius of the rod may be taken as R. Integrating n for all of the tubes gives

$$n = \frac{2Whl}{\pi R^4 \phi}. \qquad \left(\int_0^R r^3 dr = \frac{R^4}{4}\right)$$

If $T_0 = Wh$ = the moment of torsion, then

$$n = \frac{2T_0 l}{\pi R^4}.$$

The interpretation of this equation says that n, numerically, is the torque necessary to twist a rod of unit length and of unit radius through an angle of one radian.

PRACTICAL APPLICATION OF THE FOREGOING EQUATION

The last equation derived for the value of n may now be put to the experimental test by means of the apparatus shown in Fig. 165. An old lathe bed has both its head and tail stocks left on it. Into the chuck of the head stock is fastened a ball bearing axle to which is attached a light aluminum wheel with a shallow groove in its edge. The wheel can turn with negligible friction. By means of a heavy set screw *s*, one end of the rod is securely attached to the wheel. The other end of the rod is fastened in a three-jawed chuck fastened in the tail stock. Near each end of the rod is attached a small mirror in a brass frame and held on the rod by three sharp

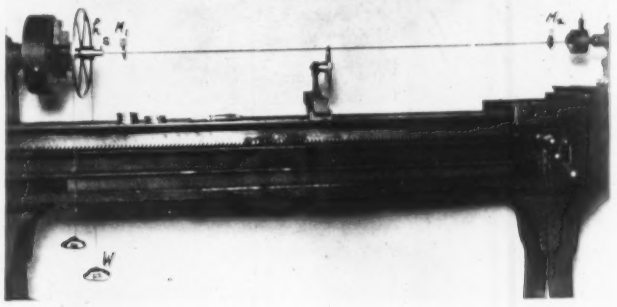

Fig. 165. A torsion lathe for measuring the coefficient of rigidity of metal rods. The twist of the rod is measured by the deflections of two beams of light, one from the mirror M_1 and the other from the mirror, M_2. Errors due to slippage in the chucks are thus obviated. b = radius of wheel over which weights W work. S is a set screw by which one end of the rod is securely attached to the wheel.

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pointed set screws. The experimental length of the rod is actually from the points of the set screws of the mirror M_1 to those of the other M_2.

In the shallow groove in the edge of the wheel is laid a cord which may be wrapped once around the wheel. On each end of the cord is attached a scale pan in which to place weights. By adding weights first to one scale pan and then to the other, a twist may be imposed on the rod which is either clockwise or anti-clockwise. From a common source of light, rays travel out to the mirrors, M_1, M_2, and are then reflected back as two spots of light to a common scale. When a load is added to one of the scalepans, mirror M_1 will be tipped more than M_2. From this differential tipping of the two mirrors it is possible to determine ϕ in our equation. The radius R of the rod is obtained by a micrometer caliper. This now gives us all the values necessary to determine n, the coefficient of rigidity.

To be continued